Implementation of CSK Communicating System With Switched SC-CNN Based Chaos Generator

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Abstract

In this study, Chaos Shift Keying (CSK) communication system, which is the first of Spread Spectrum communication samples, was realized by using different chaotic generators. This study investigates the effect of Switched State Control Cellular Neural Networks (SC-CNN) based chaotic generators on communication performance. As a result, BER / SNR performance of the CSK communication system using chaotic generators with different constructions was realized by Matlab / Simulink simulation program and performance results were obtained.

1. Introduction

Electronic circuits exhibiting chaotic behavior and chaotic oscillator circuits, which play a major role in understanding the chaos phenomena in these circuits, can be classified according to different criteria. In the literature, nonlinear oscillator circuits, which produce chaotic signals in particular, are classified as autonomous and non-autonomous chaotic oscillator circuits. Chaos generators can also be realized using CNN structures. The most important difference between known communication systems and chaos generator based digital communication systems is the increased reliability of non-periodic and unpredictable structures of chaos signals in communication systems. In chaos generator based communication systems, the use of chaos signals instead of carrier signals used in traditional communication systems is the main difference. However, the use of these signs, which are very difficult to predict, as carrier signals makes it difficult to recover the receiver circuits and makes it difficult to reach the transmitted information signal [1]. The communication system becomes complicated when the environment noise is added to this difficult situation. This increases the reliability of communication systems and makes it difficult to implement the system. The use of the chaos signal instead of the traditional sinusoidal signal as carrier signal allows the bandwidth to be increased. Digital-based communication systems have been developed that draw attention with their ease of use and all these advantages. Kolumban first introduced digital-based communication systems in 1998 [2].The most important thing about these digital communication systems is that the information signal can be obtained without synchronizing the transmitter and receiver circuits.

Digital based chaotic communication systems, *chaos shift keying* (*CSK*) [2], *chaotic on off keying* (*COOK*) [3], *differential chaos shift keying (DCSK*) [4,5], *quadrature chaos shift keying* (*QCSK*) [6] are some of these techniques. CSK communication system which is applied first among these communication systems. In this work, a CSK communication application using Switched SC-CNN based chaos signal generator is presented. In this study, it is aimed to compare BER / SNR performance of CSK communication system by using different chaos generators.

2. Chaos Generators Used in Practice

In CSK communication systems, it is considered to observe the change in BER / SNR ratio using different chaotic generators. Fort this purpose Switched SC-CNN, CNN, Sprott_94 C chaotic generators were used in this study. Let us examine these chaotic generators respectively.

2.1 Switched SC-CNN Based Chaos Generator

Among the chaotic systems, the Lorenz system is accepted as an important milestone in the analysis and examination of dynamic systems with nonlinear characteristics with unique behavior. Systems with quadratic nonlinear characteristics such as Lorenz and Chen system, Liu system and Rikitake system are preferred chaos generators in many chaos applications. On the other hand, State Controlled Cellular Neural Networks (SC-CNN) offers a flexible platform that allows for the modeling of many chaotic generators with RC based, ready to integrate, cell number and weight control. The generalized dimensionless SC-CNN state equations are as follows [7-11].

$$\begin{aligned} \dot{x}_j &= -x_j + a_j y_j + G_0 + G_s + i_j \\ \dot{y}_j &= \frac{1}{2}\left[\left|x_j+1\right| - \left|x_j-1\right|\right] \end{aligned} \tag{1}$$

Here j shows cell index, x_j and y_j represent state variable and cell output respectively, a_j is constant parameter, i_j shows threshold value of the cell, G_o shows the feedback from the output points of neighboring cells and G_s shows the feedback from the state points of neighboring cells. As can be seen from Eq. (1), the SC-CNN structure exhibits a piecewise linear output characteristic. From this point of view, it can be seen that it has a very suitable substructure in terms of modeling systems having a single variable nonlinear characteristic. On the other hand the classic SC-CNN approach seems to be inadequate when the system to be modeled has multivariable non-linear characteristics [12,13]. As a matter of fact, the Lorenz system also exhibits nonlinear characteristics of two different product types (*xz* and *xy*), as can be seen in Eq. (2).

$$\begin{aligned} \dot{x} &= a(y-x) \\ \dot{y} &= (b-z)x-y \\ \dot{z} &= xy-cz \end{aligned} \tag{2}$$

In equation (2), a, b, and c represent constants, while x, y, and z represent time-dependent variables of the system. It can also be seen from these equations that it is not possible to obtain the quadratic nonlinearity characteristic of the Lorenz system using the classical SC-CNN approach. To remove this problem equation (1) can be revised as follows.

$$\begin{aligned} \dot{x}_j &= -x_j + a_j y_j + G_0 + G_s + G_n + i_j \\ y_j &= \frac{1}{2}\left[|x_j+1| - |x_j-1| \right] \end{aligned} \tag{3}$$

The system given by Eq. (3) is in one-to-one correspondence with the structure shown in Eq. (1) except for the G_n parameter. Here, the G_n parameter represents a voltage-controlled switching parameter and j represents the cell index. The three-cell SC-CNN system obtained by Eq. (3) can be written as follows :

$$\begin{aligned} \dot{x}_1 &= -x_1 + \textstyle\sum_{k=1}^{3} a_{1k} y_k + \sum_{k=1}^{3} s_{1k} x_k + \sum_{k=1}^{3} n_{1k} x_k + i_1 \\ \dot{x}_2 &= -x_2 + \textstyle\sum_{k=1}^{3} a_{2k} y_k + \sum_{k=1}^{3} s_{2k} x_k + \sum_{k=1}^{3} n_{2k} x_k + i_2 \\ \dot{x}_3 &= -x_3 + \textstyle\sum_{k=1}^{3} a_{3k} y_k + \sum_{k=1}^{3} s_{3k} x_k + \sum_{k=1}^{3} n_{3k} x_k + i_3 \end{aligned} \tag{4}$$

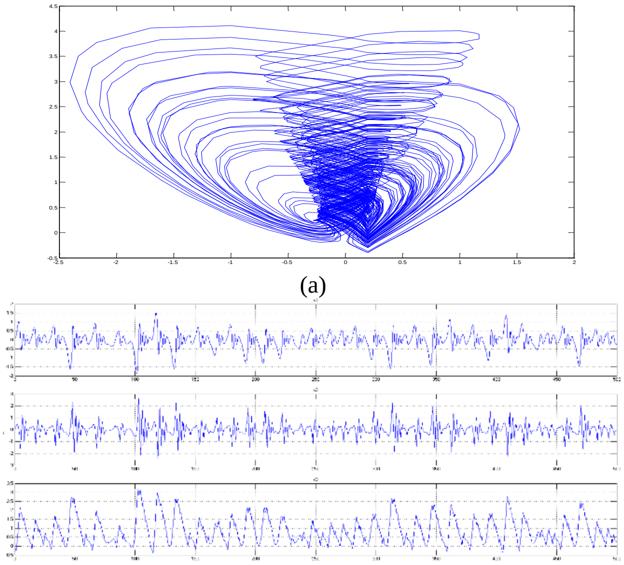
İn equation (4) *k* shows cell index, *x* represents state variable , *y* represents cell output, *a* shows the feedback coming from the output of neighboring cells, *s* shows the feedback from the state points of neighboring cells. In addition, n is a voltage controlled switching parameter. Lorenz-like system can be produced by selecting the following parameter values.

$s_{13}=s_{23}=s_{31}=s_{32}=0$, $a_{11}=a_{12}=a_{13}= a_{21}= a_{22}= a_{23}= a_{31}= a_{32}= a_{33}=0$,
$s_{11}=s_{12}=s_{21}=1$, $s_{22}=0.5$, $s_{33}=0.8$, $i_3=0.2$,
$n_{11}=n_{12}=n_{13}= n_{21}= n_{22}= n_{32}= n_{33}=0$,
$n_{23}=\text{sgn}(y_1)$, $n_{31}=\text{sgn}(x_1-i_3)$,
$$y_1 = \frac{1}{2}\left[|x_1+1| - |x_1-1| \right]$$

$$\begin{aligned} \dot{x}_1 &= -x_1 + s_{11}x_1 + s_{12}x_2 \\ \dot{x}_2 &= -x_2 + s_{21}x_1 + s_{22}x_2 + n_{23}x_3 \\ \dot{x}_3 &= -x_3 + s_{33}x_3 + n_{31}x_1 \end{aligned} \tag{5}$$

$$n_{23} = \begin{cases} +1; \ y_1 \geq 0 \\ -1; \ y_1 < 0 \end{cases} \text{ve} \, n_{31} = \begin{cases} +1; (x_1 - i_3) \geq 0 \\ -1; \ (x_1 - i_3) < 0 \end{cases}$$

In the new system, which is controlled by a n switch controlled by zero threshold voltage, $\dot{x}_2$ and $\dot{x}_3$ dynamics operate with a binary operating systems. Figure 1 shows computer simulations of Lorenz-like systems.



(a)

(b)

Fig. 1. Computer simulations of Lorenz-like systems.; (a) $x_{1(t)}$ - $x_{3(t)}$chaotic attractor, (b) $x_{1(t)}$, $x_{2(t)}$,$x_{3(t)}$ dynamics

2.2 CNN Based Chaos Generator

State Controlled CNN (SC-CNN) has been proposed in the literature to design chaos signal generators using CNN constructions [14]. When the state equations of SC-CNN structures are examined, in equation (6) x_j represents *state control*, a_j is constant parameter, i_j shows *threshold*, *j* represents cell index, G_0 represents neighboring cell output, G_s represents the connection of the neighboring cell. The output function of CNN structure is shown by equation (7).

$$\dot{x}_j = -x_j + a_j y_j + G_o + G_s + i_j \tag{6}$$
$$\dot{y}_1 = {}^1\!/_2 \left(|x_1 + 1| - |x_1 - 1| \right) \tag{7}$$

When we want to design the CNN structure given by the above equations as a three-cell structure, the obtained equations and parameter values should be as follows [15].

$$\begin{aligned} \dot{x}_1 &= -x_1 + s_{11}x_1 + s_{12}x_2 \\ \dot{x}_2 &= -x_2 + s_{22}x_2 + s_{23}x_3 \\ \dot{x}_3 &= -x_3 + s_{31}x_1 + s_{32}x_2 + s_{33}x_3 + a_{31}y_1 \end{aligned} \tag{8}$$
$s_{11}=s_{12}=s_{22}=s_{23}=1, s_{31}=-0.5, s_{32}=-0.4, s_{33}=0.5, a_{31}=1$

In the three-cell CNN equations x shows *state control*, *a* and *s* represent the constant parameters. The chaotic attractor obtained in the system simulation program is shown in Fig.2.

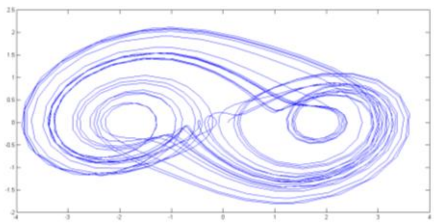


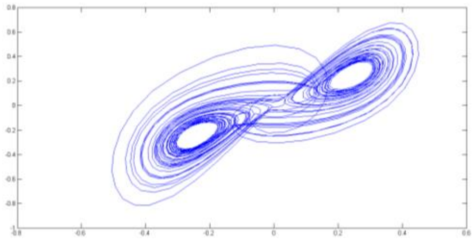
Fig. 2. Chaotic attractor in the plane x_1-$x_2$of *CNN*-based chaotic generator.

2.3 Sprott_94 C Chaos Generator

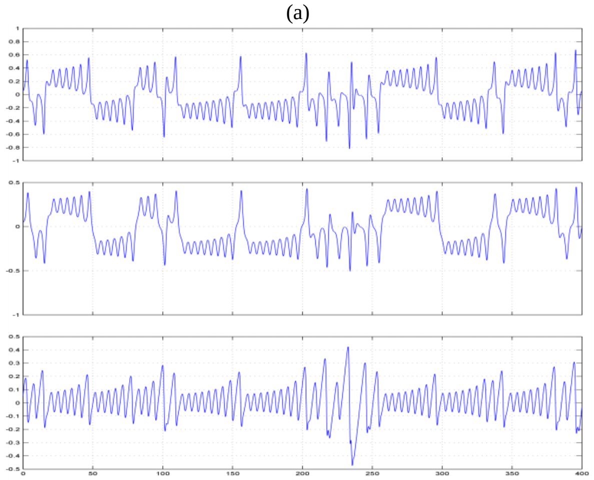
The chaos signal is the most basic structure in communication systems as well as in systems with many application fields implemented using a chaotic signal generator. From this perspective, the realization of the generated chaotic signals is gaining importance.Sprott_94_C chaos generator take attention because of its simple structure and its rich chaotic behavior. The three-dimensional dynamic system equations of the Sprott_94_C chaotic generator are shown by Eq. (9) [16].

$$\begin{aligned} \dot{x} &= yz \\ \dot{y} &= x - y \\ \dot{z} &= 1 - x^2 \end{aligned} \tag{9}$$

İn equation (9) x,y,z are state variables. Chaotic attractors of the system, which's precise initial conditions and computer simulations are given in equation (9), are shown in Fig.3.



(a)



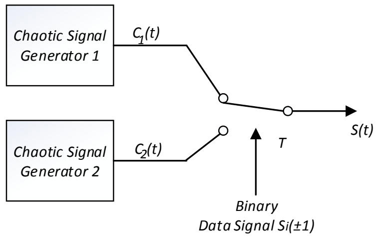
(b)

Fig. 3.Chaotic Signal obtained from realization of *Sprott C system on Matlab/Simulink Program* :(a) chaotic attractor seen on *x-y* plane, (b) $x_{1(t)}$, $x_{2(t)}$,$x_{3(t)}$ dynamics.

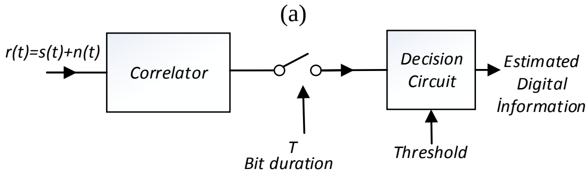
Chaotic signals were obtained by the Sprott C system, which is expressed by Eq. (9), and many application studies have been done for secure communication systems [16].

3. Chaotic Shifting Switched Communication System

CSK digital communication systems were first proposed by Kolumban in 1998 and have emerged as a model that does not require continuous synchronization. Transmitter circuit is formed by switching two different chaotic generators with different bit energy level according to the transmitted binary information signal. As shown in Figure 4, the chaotic generator used in the circuit can be realized by two different systems or by obtaining the same chaotic generator with different parameters and initial values [2].



(a)



(b)

Fig.4. a) CSK transmitter block scheme, b) CSK receiver scheme [2].

In CSK communication systems, If the information signal to be transmitted is '+1', the c1 (t) chaotic signal is transmitted to the transmission channel else If the information signal to be transmitted is '-1', the c2 (t) chaotic signal is transmitted to the transmission channel.

$$s(t) = \begin{cases} c_1(t), \text{when symbol '+1' is transmitted} \\ c_2(t), \text{when symbol ' − 1' is transmitted} \end{cases} \tag{10}$$

The signal at the transmitter circuit output given by equation (10) reaches the receiver circuit input by adding noise in the transmission environment.

$$s_{CSK}(t) = s(t) + n(t) \tag{11}$$

The $s_{CSK(t)}$ signal given by equation (11) at the receiver circuit input is correlated at the receiver input and integrated.

$$z_i = \int_T r^2(t)dt = \int_T [s(t) + n(t)]^2 dt \\ = \int_T s^2(t)dt + 2\int_T s(t).n(t)dt + \int_T n^2(t)dt \tag{12}$$

The signal at the output of the integrator is subjected to the threshold detector during the delay time period. If the obtained signal is greater than zero, it is '+1' if it is not '0'.

4. Simulink Results

Computer simulation of CSK communication system have done using different chaotic generators. The BER-SNR graph obtained with different noise ratios during computer simulation is given in Fig.5.

As seen here, the noise performances of the CNN based chaotic generators used in the CSK communication system seem to be more successful. Here, a Gaussian distribution of Fig. 5 [17] shows the bit error rates calculated by equation (13) for both communication methods.

$$BER = {}^{1}/_{2}\, erfc\left(\sqrt{\frac{E_b}{4No}\left(1+\frac{\beta No}{2E_b}\right)^{-1}}\right) \tag{13}$$

In equation (13) the integrated error is expressed by erfc, noise distribution is expressed by $N_o/2$, and modulator output bit energy is expressed by E_b [17].

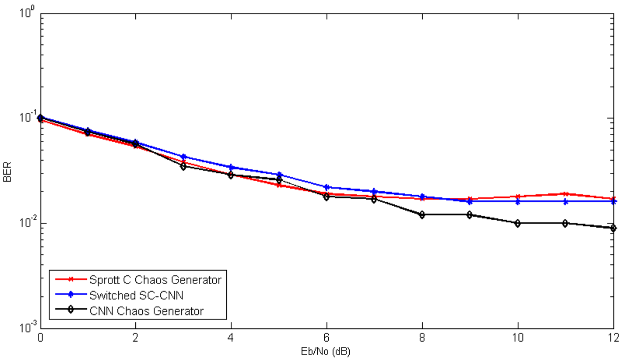


Fig.5. BER-SNR performance for different chaotic generator structures of the CSK communication system.

5. Results

In this study, the BER / SNR performance comparison of the digital chaotic communication system CSK model, which is the first of the spread spectrum communication systems, was performed using different chaotic generators. As a result of the study, CNN-based chaos generator shows better BER / SNR performance than the other structures. However, it seems that the effect of the chaos generators on the communication systems is not so much as expected. It is thought that this is related to the orthogonal structure of the chaos sign produced by the chaos generator used instead of using different chaos generators. Subsequent studies should be conducted in this direction and the results should be evaluated in the context of this study.

6. Information

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7. References

[1] Pecora, L. M., Carroll, T. L., “Synchronization in Chaotic Systems”, *Physical Review Letters*, Vol. 64, pp. 821-824,Feb.,1990.

[2] M. P. Kennedy, and G. Kolumban, “Digital communications using chaos,” Signal Processing, Vol 80, pp. 1307-1320, July 1998.

[3] Abdullah H, Valenzuela A., “Performance Evaluation of FM-COOK Chaotic Communication system”, Journal of Signal and Information Processing (JSIP), 2(3):175-177, 2011.

[4] Kolumbàn G, Vizvari G and Schwarz W., “Differential chaos shift keying: a robust coding for chaos communication”, Proceedings of International Workshop on Nonlinear Dynamics of Electronic Systems, 1(1):92-97, 1996.

[5] Majeed M. “Implementation of Differential Chaos Shift Keying Communication System Using Matlab-Simulink”. Journal of American Science, 10(10):240-244, 2014.

[6] Galias Z, and Maggio M. “Quadrature chaos-shift keying: theory and performance analysis”, *IEEE Transactions on Circuit and Systems I*, 48(12):1510-1518, 2001.

[7] Chen, G., Ueta, T., “Yet another chaotic attractor”, Int. J. Bifurcation & Chaos, Vol. 9, No. 7, pp. 1465-1466, 1999.

[8] Rikitake, T., “Oscillations of a system of disk dynamos”, Proc. R. Cambridge Philos. Soc. 54, 89-105, 1958.

[9] Chua, L. & Yang, L.,“Cellular neural networks: Theory,” IEEE Trans. Circuits Syst.35, 732–745, 1988.

[10] Chua, L. O., CNN: A Paradigm for Complexity, World Scientific Series on Nonlinear Science, Series A, Vol. 31, World Scientific Publishing, Singapore, 1988.

[11] Chua, L.O. &Roska, T., “The CNN paradigm”, IEEE Trans. Circuits &Syst-I., 40, pp.147-156, 1993.

[12] Manganaro G., Arena P., Fortuna L., Cellular Neural Networks Chaos, Complexity and VLSI Processing, Springer Series in Advanced Microelectronics, Springer, 1999.

[13] Günay, E., “MLC circuit in the frame of CNN,” Int. J. Bifurcation and Chaos20, 3267–3274, 2010.

[14] Arena, P., Baglio, S., Fortuna, L. &Manganaro, G., “Chua’s circuit can be generated by CNN cells,” *IEEE Trans. Circuits Syst*., I42, 123–125, 1995.

[15] Günay E. "A New Autonomous Chaos Generator from State Controlled Cellular Neural Networks", Int. J. Bifurcation & Chaos, Vol.22, No.3, 2012.

[16] Sprott, J. Clint. "Some simple chaotic flows." Physical review E 50.2 (1994): R647.

[17] M.Sushchik, L. S. Tsimring, and A. R. Volkovskii, “Performance analysis of correlation-based communication schemes utilizing chaos”, IEEE Trans. Circuits and Systems, vol. 47, pp. 1684–1691, 2000.